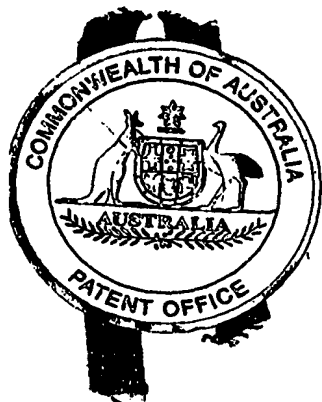REC'D **28 JUL 2004**

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J. Billingsley

JULIE BILLINGSLEY
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PROVISIONAL SPECIFICATION

FOR THE INVENTION ENTITLED:-

"MEMBRANE POST TREATMENT "

The invention is described in the following statement:-

FIELD OF THE INVENTION

The invention relates to compositions and methods for the hydrophilisation of membranes, particularly hollow fibre membranes for use in microfiltration and ultrafiltration. The invention also relates to membranes prepared in accordance with

5   these methods.

BACKGROUND ART

The following discussion is not to be construed as an admission with regard to the common general knowledge.

Synthetic membranes are used for a variety of applications including

10   desalination, gas separation, filtration and dialysis. The properties of the membranes vary depending on the morphology of the membrane i.e. properties such as symmetry, pore shape and pore size and the polymeric material used to form the membrane.

Different membranes can be used for specific separation processes, including microfiltration, ultrafiltration and reverse osmosis. Microfiltration and ultrafiltration are

15   pressure driven processes and are distinguished by the size of the particle or molecule that the membrane is capable of retaining or passing. Microfiltration can remove very fine colloidal particles in the micrometer and sub micrometer range. As a general rule, microfiltration can filter particles down to 0.1μm, whereas ultrafiltration can retain particles as small as 0.01μm and smaller. Reverse Osmosis operates on an even smaller

20   scale.

As the size of the particles to be separated decreases, the pore size of the membrane decreases and the pressure required to carry out the separation increases.

A large surface area is needed when a large filtrate flow is required. One known technique to make filtration apparatus more compact is to form a membrane in the shape

of a hollow porous fibre. Modules of such fibres can be made with an extremely large surface area per unit volume.

Microporous synthetic membranes are particularly suitable for use in hollow fibres and are produced by phase inversion. In this process, at least one polymer is

5   dissolved in an appropriate solvent and a suitable viscosity of the solution is achieved. The polymer solution can be cast as a film or hollow fibre, and then immersed in a precipitation bath such as water. This causes separation of the homogeneous polymer solution into a solid polymer and liquid solvent phase. The precipitated polymer forms a porous structure containing a network of uniform pores. Production parameters that

10   affect the membrane structure and properties include the polymer concentration, the precipitation media and temperature and the amount of solvent and non-solvent in the polymer solution. These factors can be varied to produce microporous membranes with a large range of pore sizes (from less than 0.1 to 20μm), and altering chemical, thermal and mechanical properties.

15   Microporous phase inversion membranes are particularly well suited to the application of removal of viruses and bacteria. Of all types of membranes, the hollow fibre contains the largest membrane area per unit volume.

Flat sheet membranes are prepared by bringing a polymer solution consisting of at least one polymer and solvent into contact with a coagulation bath. The solvent

20   diffuses outwards into the coagulation bath and the precipitating solution will diffuse into the cast film. After a given period of time, the exchange of the non-solvent and solvent has proceeded such that the solution becomes thermodynamically unstable and de-mixing occurs. Finally a flat sheet is obtained with an asymmetric or symmetric structure.

Hydrophobic surfaces are defined as "water hating" and hydrophilic surfaces as "water loving". Many of the polymers used in the manufacture of porous membranes are hydrophobic polymers. Water can be forced through a hydrophobic membrane, but usually only under very high pressure (150-300 psi). Membranes may be damaged at

5   such pressures and under these circumstances generally do not become wetted evenly.

Hydrophobic microporous membranes are characterised by their excellent chemical resistance, biocompatibility, low swelling and good separation performance. Thus, when used in water filtration applications, hydrophobic membranes need to be hydrophilised or "wet out" to allow water permeation. Some hydrophilic materials are

10   not suitable for microfiltration and ultrafiltration membranes that require mechanical strength and thermal stability since water molecules present in the polymer can play the role of plasticizers.

Currently, poly(tetrafluoroethylene) (PTFE), Polyethylene (PE), Polypropylene (PP) and poly(vinylidene fluoride) (PVDF) are the most popular and available

15   hydrophobic membrane materials.   Poly(ethylene-chlorotrifluoroethylene) (Halar) is another hydrophobic material showing promise as a membrane polymeric material.

Poly(vinylidene fluoride) (PVDF) is a semi-crystalline polymer containing a crystalline phase and an amorphous phase. The crystalline phase provides good thermal stability whilst the amorphous phase adds some flexibility to the membrane. PVDF

20   exhibits a number of desirable characteristics for membrane applications, including thermal resistance, reasonable chemical resistance (to a range of corrosive chemicals, including sodium hypochlorite), and weather (UV) resistance.

While PVDF has to date proven to be one of the most desirable options from among those materials suitable for microporous membranes, the search continues for

membrane materials which will provide better chemical stability and performance while retaining the desired physical properties required to allow the membranes to be formed and worked in an appropriate manner.

Given the good membrane forming properties of hydrophobic membranes and their
5 favourable mechanical and chemical properties, as well as the general familiarity in the industry with such materials, one approach to hydrophilic membranes is to synthesise membranes based around a hydrophobic polymer but with modification of the hydrophobic/hydrophilic balance of the membrane. The two main modes of modifying membrane property are (i) to modify the starting materials, reagents or conditions used to
10 produce the membrane or (ii) to modify the membrane after production (post-treatment). Combinations of the two approaches are also possible, for example, introducing components into a membrane which alone may not alter membrane function, but which do interact with reagents subsequently applied to produce a membrane with a modified property.

15 DESCRIPTION OF THE INVENTION

The present applicants have found that, in certain cases, Poly (VinylMethylEther) (PVME) can be used to modify, and in particular, reduce, the hydrophobicity of certain hydrophobic membranes. The PVME can be incorporated either by means of post-treatment, such as by soaking hollow-fibre membranes in a solution of PVME, or by
20 incorporating PVME into the dope solution for forming the membrane. Either approach could be demonstrated for a variety of reaction types, including different types of membranes such as Poly(vinylidene fluoride) (PVDF), Poly(ethylene-chlorotrifluoroethylene) (Halar) and Poly(propylene) (PP).

PVME as a post-treatment was found to make PVDF and Halar membranes hydrophilic, although the treatment was also useful on PP membranes.

PVME as a membrane additive was found to induce variations in the pore structure of PVDF such as asymmetry, as well as to impart hydrophilicity to the final

5   membrane. This was apparent for both TIPS and DIPS methods of making a membrane.

SUMMARY

According to a first aspect, the invention provides a method of hydrophilising a membrane prepared from a polymeric material, said method including the step of contacting said polymeric material with a compatible at least partially water soluble

10   polymeric hydrophilising agent.

Preferably, the at least partially water soluble polymeric hydrophilising agent is soluble in an amount of at least 5-10g/l at standard temperature and pressure. Preferably, the at least partially water soluble polymeric hydrophilising agent contains vinylmethyl ether monomers. More preferably, the polymeric hydrophilising agent is

15   polyvinylmethyl ether (PVME).

The polymeric hydrophilising agent may be a copolymer containing vinylmethyl ether monomer and at least one other co-monomer. It is preferred that the vinylmethyl ether monomer is present in an amount of at least 50 mole% of the polymeric hydrophilising agent.

20   If a co monomer is used, it is preferred if the co-monomer is selected from the group consisting of: co-polymerisable acrylate monomers and co-polymerisable vinyl monomers.

More preferably, the co-monomer is selected from the group consisting of: vinyl acetate, acrylic acid, methyl acrylate, methyl methacrylate, allyl methacrylate, ethyl

acrylate, ethyl methacrylate, methacrylic acid, fumaric acid, monoesters of fumaric acid, diesters of fumaric acid, maleic acid, monoesters of maleic acid, diesters maleic acid, diallyl maleate maleic anhydride, esters of adipic acid (divinyl adipate), ethylenically unsaturated carboxamides (acrylamide), ethylenically unsaturated carbo-nitriles

5   (acrylonitrile), ethylenically unsaturated sulfonic acids (vinylsulfonic acid).

According to a second aspect the invention provides a method of modifying the hydrophobic/hydrophilic balance of a polymer membrane prepared from a polymeric material, said method including the step of contacting said polymeric material with polyvinylmethyl ether (PVME) to produce a modified polymeric membrane.

10   Preferably the polymeric membrane is coated with PVME.

The membrane may be in the form of an ultrafiltration membrane or a microfiltration membrane

In one preferred embodiment, the polymeric material is a hydrophobic polymer and hydrophobic/hydrophilic balance of the polymer is modified to provide a hydrophilic

15   modified polymeric membrane.

For preference, the polymeric material is poly(vinylidene fluoride) (PVDF), poly(ethylene-chlorotrifluoroethylene) (Halar) and poly(propylene) (PP) or mixtures thereof. Poly(vinylidene fluoride) (PVDF) and poly(ethylene-chlorotrifluoroethylene) (Halar) are particularly preferred.

20   The polymeric material may be a formed membrane treated with a solution of PVME. Preferably, the polymeric material is treated with a solution of PVME at a concentration and for a time sufficient to allow PVME saturation of said membrane to take place. In one preferred embodiment, the polymeric material is post treated by

soaking in a solution of PVME in ethanol. In another preferred embodiment, the polymeric material is post treated by soaking in a solution of PVME in water

It is preferred that the concentration of PVME is less than 10%, more preferably less than 5% and even more preferably less than 3%, however it is preferred that the

5   concentration of PVME is greater then 0.1%.

A range of 1 to 5% is particularly preferred.

It is preferred that treatment with PVME takes place for between 5 minutes and 16 hours. Preferably, such treatment with a solution of PVME is followed by a rinsing stage to remove unbound PVME.

10   In an alternative embodiment, the polymeric material is treated with PVME by means of adding PVME to a membrane dope prior to casting. The membrane dope may be cast via a thermally induced phase separation process or by a diffusion induced phase separation process.

Preferably, the membrane dope includes PVME in an amount up to 1wt% when a

15   TIPS process is employed, or higher if a DIPS process is used. Preferably, the PVME is dissolved in a polymer dope/solvent/non-solvent mixture. More preferably, the solvent/non-solvent mixture includes a PVME solvent and PVME non-solvent

Preferably, the PVME solvent possesses weak polarity, for example, glyceroltriacteate. Preferably, the PVME non-solvent is strongly polar, for example,

20   diethylene glycol, triethylene glycol, 1,4-butanediol or mixtures thereof.

Preferably, the solvent mixture includes from 40-60% non-solvent.

Preferably, the solvent mixture includes PVME in an amount of 0.1-2wt%, and more preferably in an amount of 0.7-1wt%.

Preferably, when the method of casting is a TIPS process, it further includes treatment with a coating solution which most preferably contains a solvent and a non-solvent. When a DIPS process is used, it is preferred that N-methylpyrrolidone is present as a solvent, and water is present as non-solvent.

5   The present invention also provides a method wherein PVME is incorporated in the membrane dope and formed into a membrane, and wherein said membrane is further treated with PVME, for example the membrane is treated to cross-link incorporated and adsorbed PVME. A preferred method of cross linking is e-beam irradiation.

According to a third aspect, the invention provides a polymeric ultra or

10   microfiltration membrane incorporating PVME. The polymeric ultra or microfiltration membrane may incorporate a coating of PVME or, alternatively include a homogeneous dispersion of PVME throughout the polymer or both.

The polymeric membrane may include a heterogeneous dispersion of PVME throughout the polymer.

15   In another aspect, the invention provides a hydrophilic polymeric membrane including one or more of Halar, PVDF or PP.

In yet another aspect, the invention provides a hydrophilic polymeric membrane having a highly asymmetric structure, preferably formed from one or more of Halar, PVDF or PP.

20   PVME readily cross-links upon irradiation with electron beams or γ-radiation and is of very low toxicity, as are the starting vinyl methyl ether monomer and its degradation products. This makes it a suitable candidate for many applications requiring biocompatibility. Further, despite already possessing a low toxicity, the starting vinyl

ether monomer is readily hydrolysed at pH 7 or below and so can be readily removed, reducing even further any risk of membrane contamination by residual monomer.

PVME was surprisingly found to be effective at hydrophilising otherwise hydrophobic PP, PVDF and Halar membranes either by soaking the membrane as a post treatment or by including the PVME as a hydrophilising agent incorporated in the membrane dope. Hydrophilisation can be achieved either by soaking the membranes in a solution of PVME in a suitable solvent, for example, ethanol or water, preferably at a level greater than 0.5wt%. PVDF and Halar membranes in particular demonstrate long term stability with PVME adsorbed onto the surface, although PVME also appears to have good affinity with PP. Leaching tests show minimal leaching of PVME from the membranes after 10 days with the PVDF and Halar samples are all still hydrophilic after this period of time.

Including PVME into the dope via a TIPS process was also successful in imparting hydrophilicity to the membranes. The proportion of PVME in the dope was most preferably between 0.1 and 0.5%, although this is dependent upon the amount of non-solvent in the dope. If the proportion of non-solvent used was lower than 60wt% a larger amount of PVME could be incorporated into the dope. Surprisingly, it was found that the introduction of PVME into membrane dope induced structural changes in the membranes, such as increased asymmetry and smaller pores in addition to imparting hydrophilicity to the membrane.

PVME could also be successfully incorporated into the dope via a DIPS process. As well as modifying the hydrophilic/hydrophobic balance, the presence of PVME significantly altered the base PVDF membrane structure and suppressed the formation of macrovoids. In the case of the DIPS process, it was found desirable to employ higher

concentrations of PVDF as well as higher concentrations of PVME to achieve a high

permeability membrane with good virus/dextran retention.

PVME modified membranes can be further modified, for example, by irradiation

with electrons (e-beam). PVME is cross-linkable and under irradiation will cross-link on

5   the membrane surface. Irradiation can be applied either to membranes that have been

post-treated in PVME or to membranes that have had PVME included in the dope.

PVME may, under appropriate conditions, also cross-link with PVDF when this is

present in the membrane matrix.

PVDF and fluoropolymers with a similar structure (e.g. PVC, PVF, and PVDC)

10   are known to undergo some cross-linking upon irradiation with electrons or γ-radiation

and similar crosslinking with PVME is also possible. Those skilled in the art will

appreciate that when γ -radiation is used on fluoropolymers, caution must be taken

because there is possibility of chain scission (degradation).

Membranes with a cross-linkable hydrophilising agent in the dope may also be

15   post-treated with additional cross-linkable agent (which may be the same or different to

that used in the dope) and subsequently exposed to e-beam. This allows the adsorbed

crosslinkable agent to cross-link with the embedded PVME agent, reducing the

opportunity for the former to be desorbed from the surface.

A specific example of this is the preparation of membranes incorporating PVME

20   in the dope which are also be post-treated with an aqueous PVME solution and

subsequently exposed to e-beam irradiation. Without wishing to be bound by theory, it

is believed that this allows adsorbed PVME to cross-link with embedded PVME and be

anchored to the surface of the membrane, reducing the opportunity for the PVME to be

desorbed from the surface and dissolve into solution.

EXAMPLES

POST TREATMENT STUDIES

The post-treatment of a variety of membranes with a cross-linkable hydrophilising agent was investigated. PVDF, Halar and PP membranes were all tested.

5 For the Halar membranes, both MF (microfiltration) and UF (ultrafiltration) membranes were tested.

The general procedure for treating the pre-prepared PP and PVDF membranes was as follows:

The dry membrane was soaked in a PVME (Lutonal M40) solution with, solvent,

10 concentration and soaking time as specified. The membrane was subsequently removed from the PVME solution and placed into wash water for 4hrs. The membrane was then dried for about 4hrs

The membrane was then tested for the 'wicking' of an aqueous solution of dye and the permeability of the fibre was also tested.

15 A sample of the membrane was then soaked in water at 65°C for 1hr and the permeability of the heat-treated membrane was also tested.

The general procedure for treating the pre-prepared Halar membranes was more elaborate due glycerol-loaded pores which are present as a result of the method of production of Halar membranes. The membrane was soaked in ethanol for 12hrs,

20 followed by water for 15minutes.

The membrane was then soaked in a PVME (Lutonal M40) solution with, solvent, concentration and soaking time as specified. The membrane was subsequently removed from the PVME solution and placed into wash water for 4hrs. The membrane was then dried for about 4hrs before being resoaked in an aqueous solution of 20wt%

glycerol for 16 hr to reload the pores. The membrane was then dried for 24 hr and the permeability of the standard untreated and treated membranes was tested.

All fibres were treated as described, with various concentrations of PVME and for varying lengths of time. Tables 1 – 3 below give the results from each variation of

5   each fibre tested.

Wicking is said to have occurred occurs if a solution of dye is spontaneously absorbed into a fibre that is partially submerged vertically in such a solution and travels upwards *above* the solution meniscus. This can clearly be seen in strongly hydrophilic fibres (capillary action) but not in hydrophobic fibres. Wicking tests were not conducted

10 with the Halar fibres, as an artificial result would arise as a result of the glycerol in the pores.

TABLE 1

PVDF – Wicking and Permeability results

Fibre Type	PVDF MF	PVDF MF	PVDF MF	PVDF MF	PVDF MF
Solution Details	Ethanol wet	3wt% PVME in Ethanol	1wt% PVME in Water	0.5wt% PVME in Water	0.1wt% PVME in Water
Treatment Time	5 min	5 min	16 hr	16 hr	16 hr
Break Extension (%)	77	79	79	79	-
Fibre wicking?	No	Yes	Yes	Yes	No
Permeability after PVME treatment (LMH/bar)	1632	1966	1521	1494	No flux
Permeability after 65°C water soak (LMH/bar)	1632	1442	1635	1551	No flux

The results in Table 1 demonstrate that PVDF is made hydrophilic by PVME

5   post-treatment. Different concentrations of PVME (0-3wt%) in water or in ethanol were

investigated. The concentration of PVME in solution appears unimportant provided it is

above a certain critical value, which is believed to be about 0.1%. There would appear

to be little benefit in using more than 0.5% PVME. It is postulated that this may be

dependent upon the fibre density in the solution, or in other words the ratio of available membrane surface area to free solution, since if PVME is adsorbing to the membrane surface there is a minimum PVME quantity in solution required to obtain a totally hydrophilic membrane surface. There will simply be no room on the membrane surface for any excess PVME to adsorb and as a consequence will be washed out of the membrane upon filtration.

If too little PVME is added, the surface may not be completely hydrophilic which may in turn affect complexing and linking.

TABLE 2

PP – Wicking and Permeability results

Fibre Type	PP MF	PP MF	PP MF	PP MF
Solution Details	Ethanol wet	1wt% PVME in Ethanol	1wt% PVME in Water	0.5wt% PVME in Water
Treatment Time	5 min	5 min	16 hr	1 6hr
Fibre Wicking?	No	Yes	No	No
Permeability (LMH/bar)	2726	1339	No flux	No flux
Retreated Permeability (LMH/bar)	2726	1442	No flux	No flux

The results in Table 2 show that PP can be made hydrophilic as demonstrated by wicking (see column 2 of Table 2) but the permeability is only about half that of the standard untreated PP membrane fibre.

It appears from these results that the interaction of PP with PVME is not the
5   same as the interaction between PVDF and PVME. Without wishing to be bound by theory, it is postulated that the PVME is more strongly attracted to the PVDF surface that is slightly polar, rather than the PP surface which may be considered entirely non-polar. It seems that this affinity may be the effect that is dominating rather than that PVME is simply attracted to a hydrophobic surface in preference over solution in water.

10   TABLE 3

Halar – Wicking and Permeability results

Fibre Type	Halar MF	Halar MF	Halar UF	Halar UF
Solution Details	Ethanol wet	2wt% PVME in Water	Ethanol wet	2wt% PVME in Water
Treatment Length	5 min	16 hr	5 min	16 hr
Permeability (LMH/bar)	2039	1620	527	289

The permeability of Halar is slightly reduced as a result of PVME treatment. Generally permeability measurements for Halar MF fibre range between 1500-
15   2000LMH/bar, with Halar UF membranes varying between 200-600LMH/bar.

The results from the Halar membranes are difficult to quantify with precision because it is believed that glycerol in the pores results in lower initial clean water permeabilities that slowly increase towards a fixed value as the glycerol is completely removed from the pores. This may explain why the ethanol washed fibres have a slightly
5   higher apparent permeability, since glycerol is more readily soluble in ethanol than in water.

Halar has a mildly polar structure not dissimilar to PVDF and the affinity between Halar and PVME replicate to a degree the interaction between PVME and PVDF. The results below give an indication of the permanency of the treatment of Halar
10   membranes with PVME.

Wicking can clearly be seen in strongly hydrophilic fibres (capillary action) but not in hydrophobic fibres.

The leaching tests (Figure 1) show that the PVME is leached out initially at a high rate but this reduces over time until eventually a stable solution concentration is
15   achieved.

Leaching tests were conducted by soaking the fibres in reverse osmosis (RO) water for 240hrs. The leach water was refreshed every 24 hours (the wash water being replaced a total of 9 times) and an aliquot was analysed by UV-Vis absorption and compared against a PVME calibration curve. The results above show that there is an
20   immediate decline in the detection of PVME which this occurs for both wet and dry standards as well as for all samples. The biggest decline comes from the samples soaked in PVME, while of these samples the fibres soaked in 1wt% ethanolic PVME have the lowest starting concentration. The general trend appears to be that some PVME leaches out immediately but after approximately 48hrs there is no significant change in the

PVME level in the wash water compared to the standard. As described above however, the change in the concentration cannot be considered significant compared to the standards on the basis of this examination.

The dry standard appears at first to increase in PVME concentration initially, to a concentration that is above the sample soaked in 1wt% ethanolic PVME and the Halar sample.

An ethanol-wet standard and a dry standard were both used because there can be very small quantities of residual solvent in the PVDF membranes that are only slightly soluble in water and although very difficult to leach out entirely would nevertheless affect the UV-Vis readings. Washing with ethanol prior to UV-Vis analysis should remove any residual solvent from the membrane. This may explain why the PVDF samples appear to rise in PVME leach concentration or have a slightly higher steady-state value rather than the ethanol-wet sample. However, it is also possible that the PVME may bind more firmly to the Halar surface rather than the PVDF surface, from an aqueous solution.

The permeabilities of a number of membranes before and after PVME treatment are shown in Table 4.

In order to test the permeability after leaching, the fibres were removed from the RO water and dried at room temperature. The standard (non-treated) fibres were wet with ethanol prior to testing the permeability, while the treated fibres were simply tested with water. The results for permeability show that the fibres are still hydrophilic after this period of leaching, but that the permeabilities have dropped noticeably. This is a relatively uniform drop however and is between 40-55% across all samples including the standards, with the exception of the samples soaked in 1wt% aqueous PVME.

TABLE 4

MEMBRANE PERMEABILITY BEFORE AND AFTER PVME TREATMENT

Description	Permeability Before	Permeability After	% Change
Ethanol washed Blank – PVDF	1542	984	-36.2
1wt% PVME in Ethanol – PVDF	1442	855	-40.7
1wt% PVME in Water – PVDF	1505	307	-79.8
Dry Blank – PVDF	1542[a]	741	-51.9
1wt% PVME in Water – Halar	138	74	-46.4

[a]Since the dry blank was NOT to be treated with ethanol (including wetting out), it was

assumed that the permeabilities for the two standard samples are identical, since they are

5   obtained from the same source.

Soaking PVDF fibre membranes in PVME did not appear to modify the

mechanical properties of any of the samples in any way. Treated membranes

demonstrated the same break extensions as untreated samples.

DOPE ADDITION STUDIES

10   TIPS Membranes

PVME was added to standard TIPS PVDF or TIPS Halar dope in proportions

varying from 0 to 1wt%. The TIPS extrusion was operated in a continuous process

(although there is nothing to prohibit its use in batch processes if desired). For PVDF, PVME was dissolved into the solvent/non-solvent mixture of GTA and diethylene glycol, triethylene glycol or 1,4-butanediol. For Halar, PVME was simply dissolved in GTA. PVME is highly soluble in GTA but insoluble in more polar compounds like

5   diethylene glycol, triethylene glycol and 1,4-butanediol.

Because this mixture was between 40-60wt% non-solvent, there was a maximum amount of PVME that could be dissolved into the solvent/non-solvent mixture (approx. 0.7wt%). However, membranes formed with this proportion of PVME gave SEMs that suggested some de-mixing of PVDF was occurring. Thus, in most circumstances, it is

10   envisaged that a sub-saturation level of PVME was required.

Membranes were prepared with concentrations as a proportion of the dope mixture of 0.1-0.2wt% and their properties tested. There was no indication from any of the experiments of any thermal instability of PVME during extrusion of the membranes. Table 5 below shows the details of the different TIPS membranes.

15

TABLE 5 DETAILS OF TIPS MEMBRANES PREPARED WITH PVME IN DOPE

	0.1wt% PVME	0.2wt% PVME	0.5wt% PVME	1wt% PVME	0.5wt% PVME	1wt% PVME
Polymer Type	50/50 Solef 1015 – Kynar 461	50/50 Solef 1015 – Kynar 460	50/50 Solef 1015 – Kynar 450	Solef 1015	Halar 901	Halar 901
Polymer Concentration (wt%)	24	24	24	18	18	18
Solvent-Non-solvent	GTA – Diethylene glycol	GTA – Diethylene glycol	GTA – Diethylene glycol	GTA – Diethylene glycol	GTA	GTA
Solv./Non-solv. Ratio (wt%)	40:60	40:60	45:55	40:60	100	100
Coating Solvent	Triacetin	Citroflex 2	Triacetin	Triacetin	GTA	GTA
Coating Non-solvent	Diethylene Glycol	Triethylene Glycol	Citroflex 2	Diethylene Glycol	-	-
Coating Solv./Non-solv. Ratio (wt%)	68:32	45:55	90:10	50:50	100	100
Quench Type	Water	Water	PEG 200	Water	Water	Water
Break Extension (%)	152	228	35	-	156	173
Break Force/unit area (N/mm^2)	5.1	7.08	2.98	-	5.94	5.59
Permeability (LMH/bar)	4838	1440	301	-	1367	707
Bubble Point (kPa)	250	390	460	-	450	200
Fibre Wicking	Partially	Yes	Yes	Yes	-	-

The differences between the structures of the membranes, as observed by SEM

for the samples with and without PVME are only minor for 0.1 and 0.2wt%. These can

5   be seen in Figures 2 and 3. Slightly larger than average cells within the structure can be

seen in the SEMs of samples that have been prepared with PVME. However at about

0.5wt% some immiscibility is apparent and there is some de-mixing occurring. At the

1wt% level this de-mixing has become more extreme. In the case of PVDF, this is most

likely due to the high proportion of non-solvent used in the dope mixture to extrude the membrane fibres. In the case of Halar, which can be seen in Figure 4, demixing is most likely due to immiscibly with the base polymer (Halar) as there is no non-solvent present.

5   However such a high proportion of PVME does not appear to be necessary to impart hydrophilicity to the fibres. 0.1wt% appears sufficient to commence hydrophilising the membrane, but at this level there appears to be some portions of the fibres that were *not* hydrophilic; that is to say that upon immersion in water only sections of the fibre could be seen to wet out, while some sections remained dry, but would wet

10   with the assistance of ethanol. However, with 0.2wt% PVME present in the fibre complete hydrophilisation appeared to have taken place.

It is also noted that higher proportions of PVME in the membrane appear to cause a greater degree of asymmetry, which up to a point is a desirable property in MF and IF membranes. Although the samples with 0.5 and 1wt% PVME show evidence of

15   de-mixing as discussed earlier, they also show a high degree of asymmetry which can be attributed directly to the PVME in the structure. In addition this de-mixing can be used to induce small pores by working as a nucleating agent and encouraging phase separation. The relationship between asymmetry and PVME content is demonstrated by the trend toward increasing bubble point as the PVME content increases.

20   In summary, incorporating PVME into the dope in TIPS trials was successful in imparting hydrophilicity to the membranes. The proportion of PVME used was most preferably between 0.1 and 0.5%, although this is dependent upon the amount of non solvent in the dope. If the proportion of non solvent used was lower than 60wt%, a larger amount of PVME could be incorporated into the dope. However, the preferred

range recited above is sufficient in most cases to begin to induce structural changes in

the membrane such as asymmetry and smaller pores, as well as cause the membrane to

be hydrophilic.

DIPS Membranes

5   Three dopes were prepared with the compositions listed in Table 6 below. Two

different proportions of PVME (0.1wt% and 2.5wt%) were compared with a DIPS

PVDF dope that contained poly(vinylpyrrolidone-vinylacetate) (S630) as an alternative

additive. These fibres were all extruded in an identical manner and the results are

compared below.

10 TABLE 6

Dope Properties			
	Standard	0.4wt% PVME	2.3wt% PVME
PVDF Conc. (wt%)	13	13	13
S630 Conc. (wt%)	2.6	0	0
PVME Conc. (wt%)	0	0.4	2.3
Pore Forming Agent Conc. (wt%)	3	3	3
Water Conc. (wt%)	2	1.8	2.3
NMP Conc. (wt%)	79.4	81.8	79.4
Fibre Properties			
	Standard	0.4wt% PVME	2.3wt% PVME
Break Extension (%)	182	217	260
Break Force (N)	0.78	1.03	1.32
Break Force/mm^2 (N/mm^2)	3.81	4.83	4.12
Permeability (LMH/bar)	620	134	359
Bubble Point (kPa)	300	500	500
Fibre Wicking	Yes	Yes	Yes

   The fibres show an increase in break extension, break force and bubble point by

when PVME was added. Without wishing to be bound by theory, these increases may be

partly due to a viscosity effect in that replacing S630 with PVME results in a more

15 viscous dope which may in turn lead to fewer macrovoids and a more robust structure,

giving a higher break force and break extension, and also possibly contributing to the increase in bubble point. The variation in permeability is possibly due to the change in water (non-solvent) concentration between the samples.

The SEMs in Figure 5 demonstrate the trend apparent from the fibre properties –

5   adding PVME to the structure decreases the formation of macrovoids. Less than a 0.4wt% replacement of S630 with PVME is required to induce a dramatic change in properties however, as demonstrated by the DIPS examples.

All samples wicked water quite thoroughly, and there was no difference observed from the hydrophilicity of the standard formulation. The permeability measurements

10   were conducted without a 'wetting' step – a manual wetting out of the membrane with ethanol. The permeability of 2.3wt% PVME samples appears to increase over 0.4wt% PVME samples. Since the bubble point is the same for these two samples while permeability varies, it can be seen that increasing the PVDF concentration and adding different PVME concentrations allow a UF membrane with a high permeability to be

15   produced.

DATED THIS 8th DAY of JULY 2003

BALDWIN SHELSTON WATERS

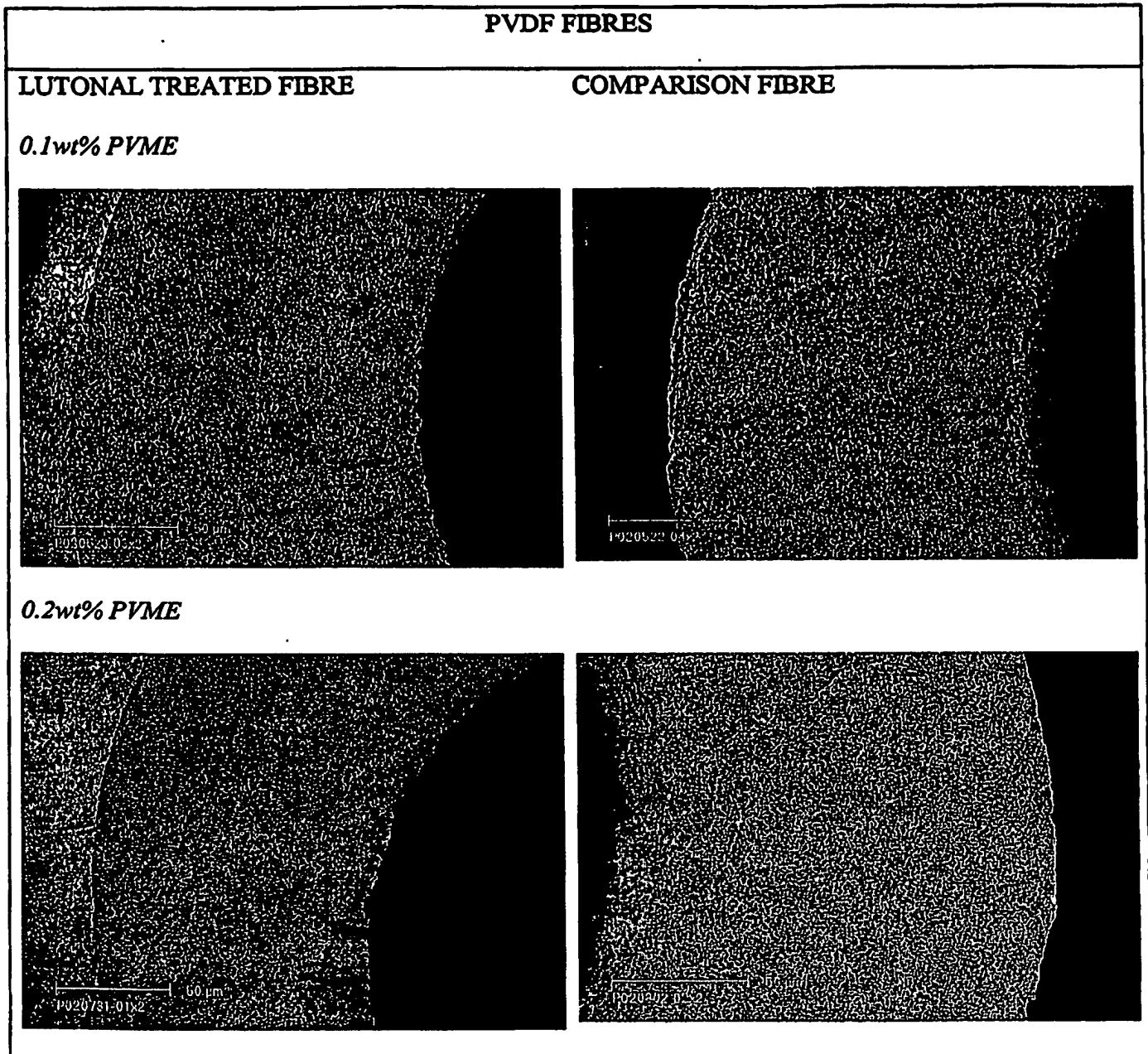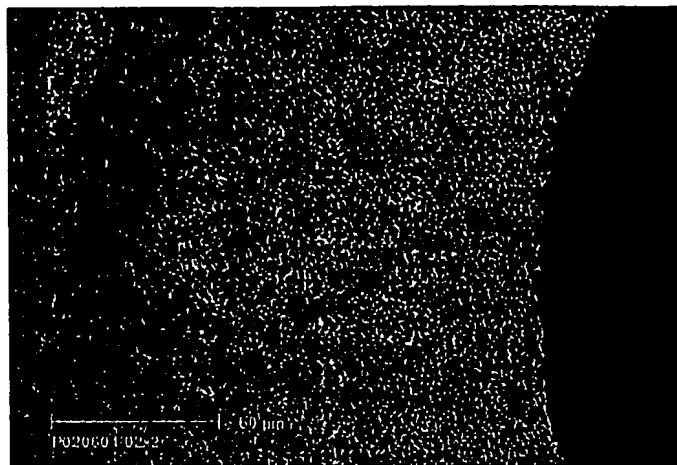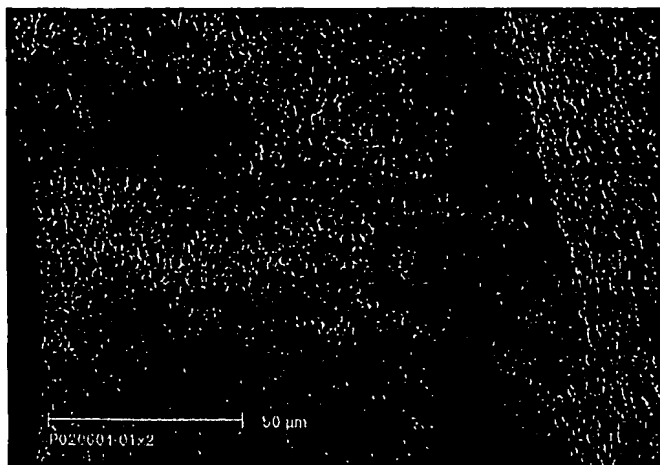Attorneys for U.S. FILTER WASTEWATER GROUP, INC.

FIG 1

Lutonal Leachate over Time

FIG 2

PVDF FIBRES	
LUTONAL TREATED FIBRE	COMPARISON FIBRE

0.1wt% PVME

0.2wt% PVME

FIG 3

FIG 4

Halar Fibres

LUTONAL TREATED FIBRE

COMPARISON FIBRE
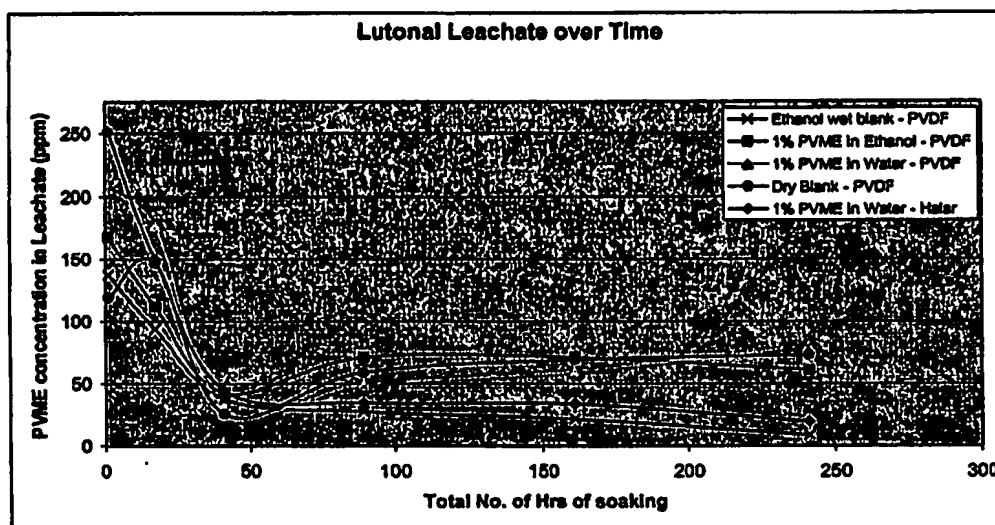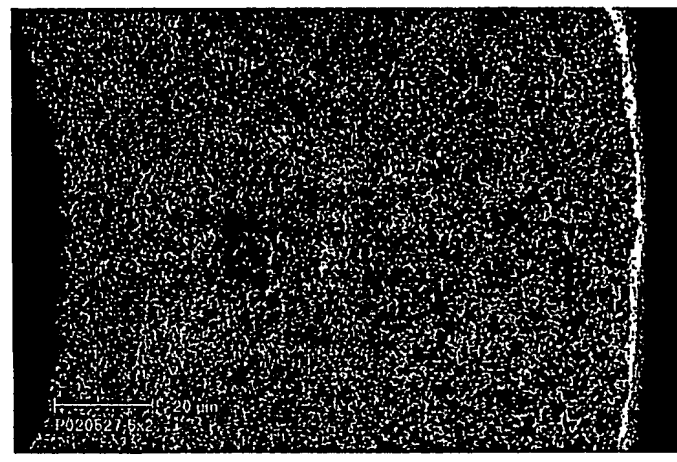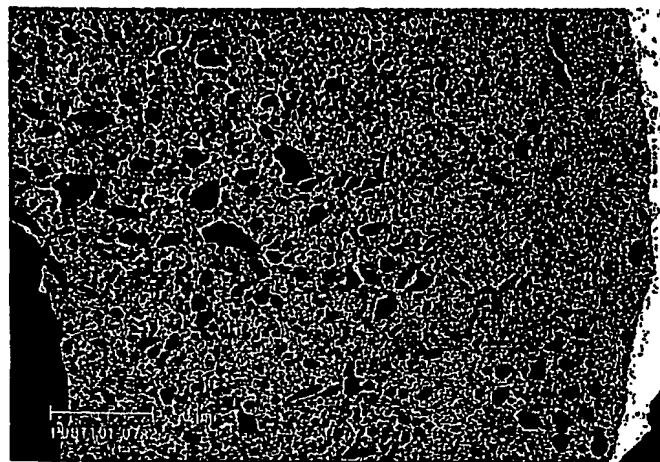
0.5wt% PVME

1wt% PVME
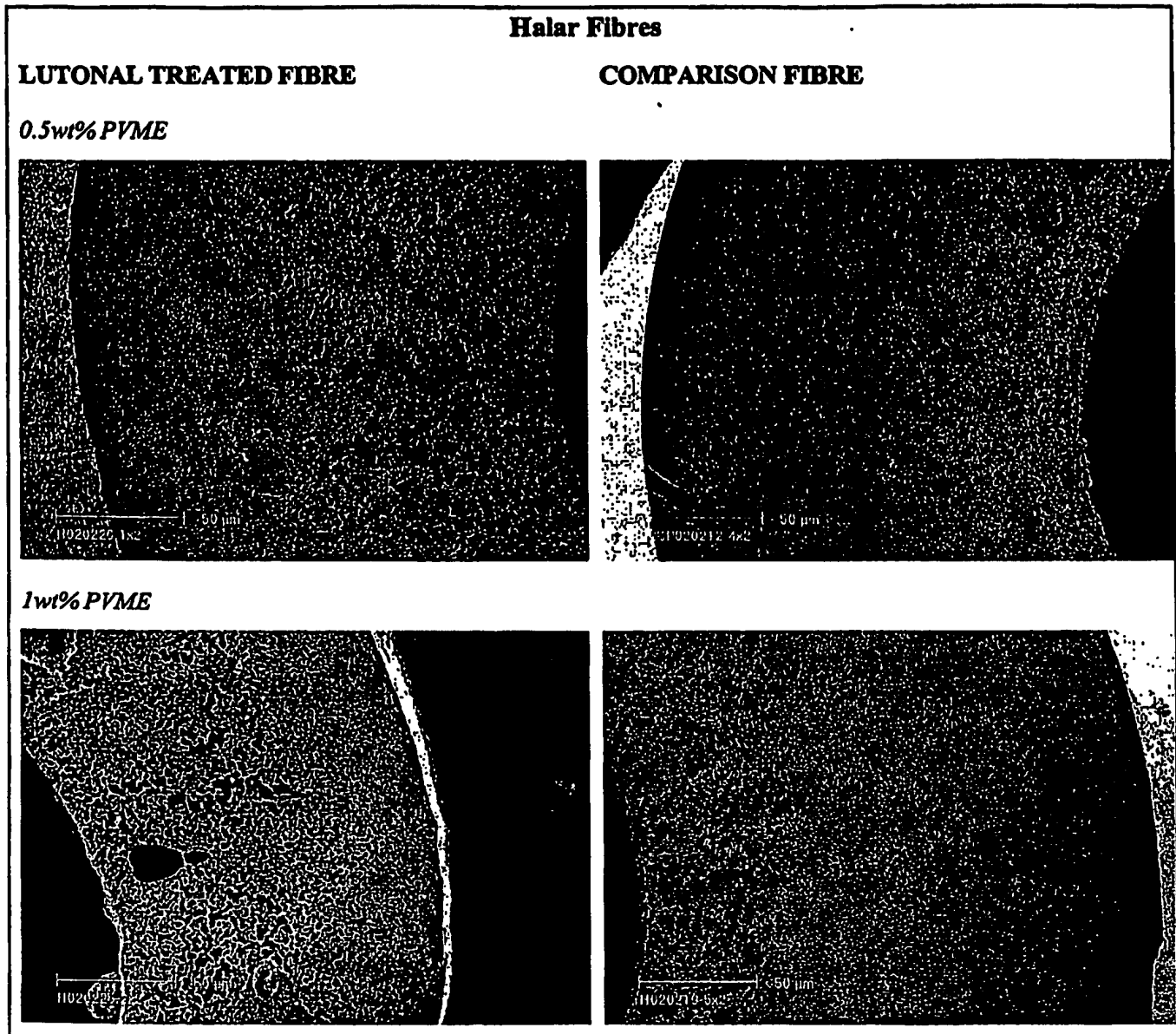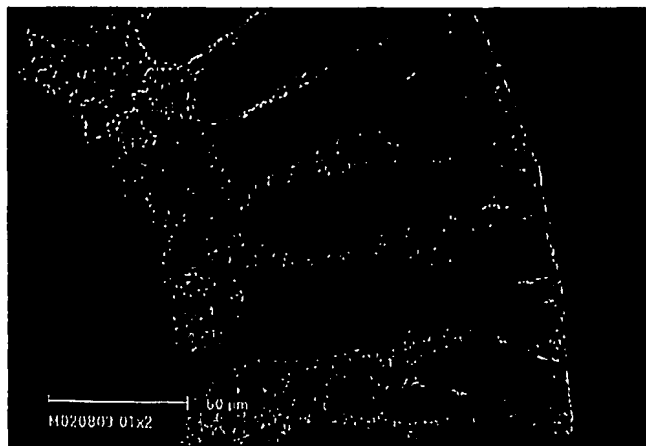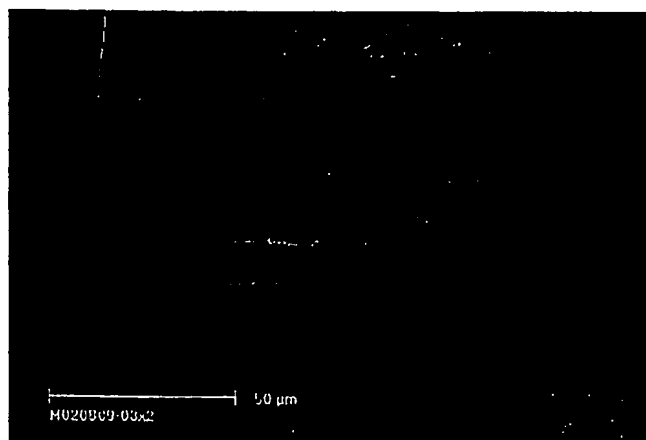
FIG 5
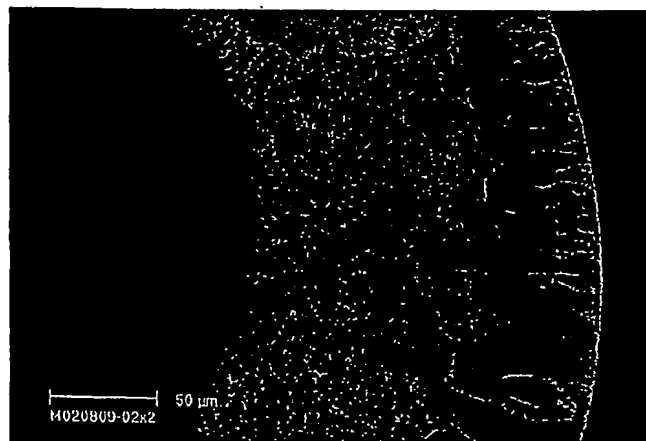
a)   Standard Fibre (no PVME)

b)   0.4% PVME

c)   2.3wt% PVME

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